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The Impact of Alternative Fuels on Fuel Consumption and Exhaust Emissions of Greenhouse Gases from Vehicles Featuring SI Engines

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Abstract

Various alternative fuels are candidates for partial or total replacement of fossil fuel for spark ignition (SI) engines used in the transport sector. These include ethanol (already in use in blends), compressed natural gas (CNG) (popular in certain markets) and liquid petroleum gas (LPG) (popular in other markets). These fuels are all suitable for use in SI engines, but their physicochemical parameters differ from those of standard petrol. Specifically, their carbon weight fraction and the energy density differ significantly; these two factors (among others) strongly control fuel consumption and exhaust emissions of greenhouse gases (GHG), including carbon dioxide (CO_2).
This study considers chassis dynamometer data obtained under laboratory conditions. Results from the literature and from experiments conducted by the authors show a range of responses in terms of exhaust emissions of GHG for different fuel types. CNG in particular shows low CO_2 emissions, but ethanol blends show virtually no change in CO_2 emissions and an increase in volumetric fuel consumption.

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Keywords: alternative fuel; greenhouse gas; carbon dioxide; automotive engine; biofuel; compressed natural gas

Introduction: alternative fuels in SI engines

The transport sector continues to account for a large share of humanity's total energy usage; the road transport sector is characterised by near-total reliance on fossil fuels. Alternative fuels currently in use and under consideration are still carbon based. The result of this is that around 20% of all carbon dioxide (CO_2) emissions in the European Union (EU) come from road transport. Emissions of greenhouse gases from road vehicles remain very high on the political agenda; concern over the impact of vehicles on air quality remains high. Looking to the longer term, the security of the oil supply and broader energy usage concerns have become very much part of the automotive development landscape. Concern over gaseous and solid emissions – most infamously CO_2, but there are also many others – has become a concern for all global automotive markets, not just the USA and the EU.

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The response to this has been the introduction of various pieces of legislation, some imposing increasingly strict emissions limits; others various mandates, incentives and quotas regarding fuel consumption and the types of fuels used. Vehicle technologies have also changed, resulting in quite remarkable progress in reductions in CO_2 emissions and fuel consumption in recent years [1,2], although there is a large body of evidence that emissions measured in the laboratory are not the same as those is observed during real on-road usage (see [2] and references therein).

Exhaust emissions of greenhouse gases

However, exhaust emissions of greenhouse gases are not limited to CO_2; methane (CH_4) and nitrous oxide (N_2O) both have global warming potentials much greater than unity. Methane is commonly measured in exhaust emissions testing, since EU legislation sets limits for total hydrocarbons and non-methane hydrocarbons (the difference being methane itself). N_2O is regulated in the USA. Notwithstanding the large global warming potential (GWP) values for CH_4 and N_2O, the mass of these gases emitted is typically around 4 orders of magnitude below the mass of CO_2 emitted over a given driving cycle. N_2O can be formed as an unwanted by-product in exhaust gas aftertreatment systems – around 55% of all N_2O emissions from transport are formed in this way [3]. N_2O emissions can have a global warming impact as much as 1%-3% of that of CO_2 emissions from a given vehicle [4]. Data and commentary on N_2O emission factors from modern light-duty vehicles can be found in [5] and [6]; see [7] for a report of recent fieldwork on emissions of CH_4, N_2O, CO_2 etc from vehicles. Montzka et al. [8] present an analysis of the impact of greenhouse gases other than CO_2 on climate change. While CH_4 emissions *from an engine* are higher when running on CNG, LPG and ethanol, new bi-fuel *vehicles* for sale in markets such as the EU have to met emissions limits on both fuel types, in which case CH_4 emsissions are very low – the EU's Euro 5/6 CH_4 limit is effectively 32 mg/km for passenger cars. (These low emissions limits can be reached by employing specially designed catalytic exhaust gas aftertreatment systems and by creating a suitable engine calibration.) Hence, this additional CH_4 from the engine is oxidised to CO_2 (and H_2O) and so can be taken into consideration by focusing on CO_2 emsisions from the vehicle's exhaust. Aftermarket conversions and usage of ethanol blends in unmodfied verhicles is, however, another matter. Having mentioned the topics of emission of CH_4 and N_2O, this paper will now focus on CO_2 and fuel consumption.

Fuel and energy consumption

Emissions results themselves are important indications of the energy efficiency of a vehicle, most of all CO_2 (units [g/km]). Volumetric fuel consumption [l/100km] is a partial function of the density of the fuel type (which is of course massively different for gaseous and liquid fuels), and so units of [kg/100km] can be used to factor out these differences in density. Since certain alternative fuels have very different chemistries from their hydrocarbon equivalents (e.g. ethanol vs petrol hydrocarbons, where the former contains an oxygen atom), it can be illuminating to give results in terms of energy consumption [MJ/100km]. A distinction must be made between tank-to-wheel emissions (exhaust emissions) and full fuel life-cycle emissions, of which exhaust emissions are only a part. Exhaust emissions testing considers only emissions originating from the exhaust during operation of the vehicle. However, they form part of full life-cycle emissions and are worthy of study in this context.

In the simplest terms, energy consumption is a function of the physical quantity of fuel used, the efficiency of the combustion process and the energy density of the fuel type: $E = \frac{Q \times d_{energy}}{e}$, where Q is the total quantity of fuel leaving the vehicle's fuel storage system during the driving cycle, d_{energy} is the energy density of the fuel type used and e is the mean efficiency of the engine during the driving cycle, which can be fuel-dependent. Usage of alternative fuels (even in the blended form) typically changes all three of these parameters simultaneously. In the case of SI engines, the knock resistance (octane rating) of the fuel *can* have a noticeable impact on the value of e. (Ethanol and methane both have high octane numbers.) When analysing energy consumption over driving cycles (see [9] for a detailed discussion), it is important to remember two types of losses: cold start and idling. A comparison of some emisions and consumption data from the literaure and from comparable experiemtnal work conducted by the authors is presented in Table 1.

Fuel	Compared to….	Impact on… [%]			
		CO_2 emissions	Volumetric FC	Gravimetric FC (calculated)	Energy consumption (calculated)
CNG	Standard E0 petrol	-24 [10]	--	--	Comparable
LPG		-15		--	Comparable
E5		Insignificant	+1 (calculated from data in [11])	+1	Comparable
E10		Insignificant [11]; 0 [12]	+3.5 [13]; +4 [11]	+4	Comparable
E25		Limited [11]	+7; +10 [13]	+10	Comparable
E50		Limited [11]	+20 [11]	+24	Comparable
E85 (in FFVs)		-2 [14] -4 [12] -9 [15]	+25-26 [16],	+32	Comparable [17]

Table 1. A parameter-based comparison of various alternative fuels suitable for use in SI engines in comparison to standard petrol. Figures without a reference are BOSMAL data or the results of calculations; the source may be considered to be this study

For real-world usage, the fuel/energy consumption penalties for ethanol blends may be somewhat higher, due to cold start difficulties and excess fuelling. Over a cycle as long as the NEDC, the energy consumption for CNG and petrol appears comparable. For shorter cycles, this may not be the case; certain results indicate a *very slight* increase in energy consumption when running on CNG, possibly due to the total lack of fuel-mediated lubrication when running on a gaseous fuel.

Conclusions

Of the alternative fuels and blends considered here, only CNG and LPG have advantages in terms of reduced exhaust CO_2 emissions. All ethanol blends have similar or identical CO_2 emissions to standard petrol, but increased volumetric and gravimetric fuel consumption (rising to a very high level for high blends such as E85). Given the repeatability and uncertainty inherent in exhaust emissions testing, it should be concluded that no detectable differences in energy consumption result from using different fuels in vehicles designed for their use. An exception to this would be, for example, usage of E85 in an unmodified vehicle, which can cause excess energy consumption due to inefficient combustion [11]. Exhaust emissions only form part of the total fuel life-cycle emissions for a given fuel (see [18]), but

CNG and LPG have undeniable advantages in terms of exhaust CO_2 emissions; for ethanol blends the environmental performance depends fully on the origin of the ethanol and the sustainability and energy intensity of its production process.

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